1.0 BENCHMARK STUDIES

1.1 STUDY OBJECTIVES

The Benchmark Studies represents the base condition for the operation of the Oroville–Thermalito Complex. Impacts of any proposed resource management actions will be evaluated in terms of changes from the base conditions.

Two benchmark studies were developed to characterize existing and future base conditions. The Benchmark Study (Existing Conditions) uses the current level-of-development hydrology as well as the current regulatory framework (which includes the existing biological opinions for steelhead and spring-run Chinook salmon). The Benchmark Study (Future Conditions) uses assumed year 2020 level-of-development hydrology as well as reasonably anticipated future facilities as a part of or effecting the operations of the Central Valley Project and the State Water Project.

1.2 METHODOLOGY AND TOOLS

For Oroville Facilities Relicensing, the base conditions (existing and future) described in the Benchmark studies are a combination of simulated conditions from the following three models: CALSIM II, HYDROPS, and WQRRS.

- CALSIM II is a State Water Project/Central Valley Project simulation tool utilizing a 73-year sequential synthetic hydrology and monthly time step. CALSIM II provides the system wide mass balance simulation accounting for the various pressures and influences on the operations of Oroville Facilities that may occur outside the study area of the Relicensing effort.
- HYDROPS is an hourly optimization model with a one-week time horizon. Using weekly operational boundary conditions developed from the disaggregated monthly results of CALSIM II, HYDROPS™ optimizes revenue based on generation from the Oroville Facilities while meeting all facilities constraints and operational requirements.
- WQRRS simulates water temperatures throughout the Oroville Facilities and Feather River based on the hourly flow output from HYDROPS. Note that the flow-stage relationships used in the WQRRS were developed in the Feather River flow-stage model (a HEC-RAS-based model), assuming the existing configuration of river channels and relevant facilities.

Two CALSIM II simulations serve as the foundation for the Benchmark studies, one representing existing conditions and one representing future conditions circa 2020. The synthetic hydrology used with CALSIM II and the outputs from the CALSIM II runs were disaggregated from monthly values to weekly values and serve as inputs to the HYDROPS runs. HYDROPS output and some additional CALSIM II hydrology and output were used as inputs for WQRRS. Through an iterative process, WQRRS was used to identify additional constraints for the HYDROPS model runs. The results from the CALSIM II simulations, the last iterations of WQRRS, and the final HYDROPS runs together serve as the Benchmark Scenarios.

1.2.1.1 CALSIM II

CALSIM II is a monthly time-step simulation model of the combined California State Water Project (SWP) and the Bureau of Reclamation's Central Valley Project (CVP) systems and areas tributary to the Sacramento-San Joaquin Delta. This includes important non-project facilities on the east side of the Central Valley. CALSIM II is designed to be used for SWP/CVP planning purposes. For a given simulation the model adopts a static depiction of land use, water management facilities and their operational rules and constraints and applies them over a synthetic 73-year hydrology based on water years 1922 through 1994.

The geographic coverage of CALSIM II includes the valley floor drainage area of the Sacramento and San Joaquin Rivers, the upper Trinity River, and the San Joaquin Valley, Tulare Basin, and southern California areas served by the SWP. The focus of CALSIM II is on the major CVP and SWP facilities, but operations of many other facilities are included to varying degrees.

CALSIM II determines an optimal set of decisions for each time period given a set of weights and system constraints to route water through a network. The user can specify the physical system (dams, reservoirs, channels, pumping plants, etc.), operational rules (flood-control diagrams, minimum flows, delivery requirements, etc.), and priorities for allocating water.

CALSIM II is the replacement for the PROSIM/SANJASM (USBR) and DWRSIM (DWR) models. CALSIM II includes a variety of model enhancements to better characterize and simulate the operations of the CVP and SWP systems. CALSIM II, developed through a collaborative effort by DWR and Reclamation, represents a comprehensive simulation of the SWP and CVP. The Benchmark Study Team (BST) under the direction of the CALFED/DWR/USBR Technical Coordination Team (TCT), DWR and Reclamation management has conducted technical reviews and refinements. The TCT was formed early in 2001 to coordinate the efforts of various programs in the development of CALSIM II analyses of the water management options identified in the CALFED Record of Decision. The BST was formed following the release of the sample studies in September 2001.

The Benchmark studies include the Existing Condition (2001 LOD) and Future Condition (2020 LOD) simulations. Each condition was simulated with DWR's ANN model for modeling Delta flow-salinity relationships. A listing of the major assumptions associated with these benchmark studies is summarized in Table 1.

Table 1 Summary of Assumptions for CALSIM II Benchmark Studies

	Existing Conditions	Future Conditions
Period of Simulation	73 years (1922-1994)	Same
HYDROLOGY		
Level of Development (Land Use)	2001 Level, DWR Bulletin 160-98[1]	2020 Level, DWR Bulletin 160-98
Demands		
North of Delta (except American R)		
CVP	Land Use based, limited by Full Contract	Same
SWP (FRSA)	Land Use based, limited by Full Contract	Same
Non-Project	Land Use based	Same
CVP Refuges	Firm Level 2	Same
American River Basin		
Water rights	Fixed annual demands	Fixed annual demands as projected for 2020 by Water Forum Analysis
CVP	Fixed annual demands	Fixed annual demands as projected for 2020 by Water Forum Analysis but modified with PCWA 35 TAF CVP contract supply diverted at the new American River PCWA Pump Station
San Joaquin River Basin		
Friant Unit	Regression of historical	Same
Lower Basin	Fixed annual demands	Same
Stanislaus River Basin	New Melones Interim Operations Plan	Same
South of Delta		
CVP	Full Contract	Same
CCWD	124,000 AF/YR[2]	158,000/YR[3]

[1] 2000 Level of Development defined by linearly interpolated values from the 1995 Level of Development and 2020 Level of Development from DWR Bulletin 160-98

[2] Delta diversions include operations of Los Vaqueros Reservoir and represents average annual diversion

	Existing Conditions	Future Conditions
SWP (w/ North Bay Aqueduct)	3.0-4.1 MAF/YR	3.3-4.1 MAF/YR
SWP Article 21 Demand	MWDSC up to 50,000 month/month, Dec-Mar, others up to 84,000 month/month	Same
FACILITIES		
Freeport Regional Water Project	None	Included[4]
Banks Pumping Capacity	6680 cfs	8500 cfs
Tracy Pumping Capacity	4200 cfs + deliveries upstream of DMC constriction	4600 cfs w/ intertie
REGULATORY STANDARDS		
Trinity River		
Minimum Flow below Lewiston Dam	368,600-452,600/YR	Trinity EIS Preferred Alternative (368,600-815,000/YR)
Trinity Reservoir End-of-September Minimum Storage	Trinity export-to-inflow Preferred Alternative (600,000 AF as able)	Same
Clear Creek		
Minimum Flow below Whiskeytown Dam	Downstream water rights, 1963 USBR Proposal to USFWS and NPS, and USFWS use of CVPIA 3406(b)(2) water	Same
Upper Sacramento River		
Shasta Lake End-of-September Minimum Storage	SWRCB WR 1993 Winter-run Biological Opinion (1.9 Million AF)	Same
Minimum Flow below Keswick Dam	Flows for SWRCB WR 90-5 and 1993 Winter-run Biological Opinion temperature control, and USFWS use of CVPIA 3406(b)(2) water	Same
Feather River		
Minimum Flow below Thermalito Diversion Dam	1983 DWR, DFG Agreement (600 CFS)	Same
Minimum Flow below Thermalito Afterbay outlet	1983 DWR, DFG Agreement (1000 – 1700 CFS)	Same
American River		
Minimum Flow below Nimbus Dam	SWRCB D-893 (see accompanying Operations Criteria), and USFWS	Same

[3] Same as footnote 2

[4] Includes modified EBMUD operations of the Mokelumne River

	Existing Conditions	Future Conditions
	use of CVPIA 3406(b)(2) water	
Minimum Flow at H Street Bridge	SWRCB D-893	Same
Lower Sacramento River		
Minimum Flow near Rio Vista	SWRCB D-1641	Same
Mokelumne River		
Minimum Flow below Camanche Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (100 – 325 CFS)	Same
Minimum Flow below Woodbridge Diversion Dam	FERC 2916-029, 1996 (Joint Settlement Agreement) (25 – 300 CFS)	Same
Stanislaus River		
Minimum Flow below Goodwin Dam	1987 USBR, DFG agreement, and USFWS use of CVPIA 3406(b)(2) water	Same
Minimum Dissolved Oxygen	SWRCB D-1422	Same
Merced River		
Minimum Flow below Crocker-Huffman Diversion Dam	Davis-Grunsky (180 – 220 CFS, Nov – Mar), and Cowell Agreement	Same
Minimum Flow at Shaffer Bridge	FERC 2179 (25 – 100 CFS)	Same
Tuolumne River		
Minimum Flow at Lagrange Bridge	FERC 2299-024, 1995 (Settlement Agreement) (94,000 – 301,000/YR)	Same
San Joaquin River		
Maximum Salinity near Vernalis	SWRCB D-1641	Same
Minimum Flow near Vernalis	SWRCB D-1641, and Vernalis Adaptive Management Program per San Joaquin River Agreement	Same
Sacramento River-San Joaquin River Delta		
Delta Outflow Index (Flow and Salinity)	SWRCB D-1641	Same
Delta Cross Channel Gate Operation	SWRCB D-1641	Same
Delta Exports	SWRCB D-1641, USFWS use of CVPIA 3406(b)(2) water	Same
OPERATIONS CRITERIA		
Subsystem		
Upper Sacramento River		

	Existing Conditions	Future Conditions
Flow Objective for Navigation (Wilkins Slough)	3,250 – 5,000 CFS based on Lake Shasta storage condition	Same
American River		
Folsom Dam Flood Control	SAFCA, Interim Re-operation of Folsom Dam, Variable 400/670 (without outlet modifications)	Same
Flow below Nimbus Dam	Operations criteria corresponding to SWRCB D-893 required minimum flow	Same
Sacramento Water Forum Mitigation Water	None	Sacramento Water Forum (up to 47,000/YR in WFA drier and driest years)[5]
Feather River		
Flow at Mouth	Maintain the DFG/DWR flow target above Verona or 2800 cfs for Apr – Sep dependent on Oroville inflow and FRSA allocation	Same
Stanislaus River		
Flow below Goodwin Dam	1997 New Melones Interim Operations Plan	Same
San Joaquin River		
Flow near Vernalis	San Joaquin River Agreement in support of the Vernalis Adaptive Management Program	Same
System-wide		
CVP Water Allocation		
CVP Settlement and Exchange	100% (75% in Shasta Critical years)	Same
CVP Refuges	100% (75% in Shasta Critical years)	Same
CVP Agriculture	100% - 0% based on supply	Same
CVP Municipal & Industrial	100% - 50% based on supply	Same
SWP Water Allocation		
North of Delta (FRSA)	Contract specific	Same
South of Delta	Based on supply; Monterey Agreement	Same
CVP/SWP Coordinated Operations		
Sharing of Responsibility for In-Basin-Use	1986 Coordinated Operations Agreement	Same
Sharing of Surplus Flows	1986 Coordinated Operations Agreement	Same
Sharing of Restricted Export Capacity	Equal sharing of export capacity under SWRCB D-1641; use of CVPIA 3406(b)(2) only restricts CVP	Same

[5] This is implemented only in the PCWA Middle Fork Project releases used in defining the CALSIM II inflows to Folsom Lake

	Existing Conditions	Future Conditions
	exports; EWA use restricts CVP and/or SWP exports as directed by CALFED Fisheries Agencies	
Transfers		
Dry Year Program Phase 8 MWDSC/CVP Settlement Contractors	None None None	Same Same Same
CVP/SWP Integration		
Dedicated Conveyance at Banks	None	SWP to convey 100,000 AF of Level 2 refuge water each year at Banks PP.
NOD Accounting Adjustments	None	CVP to provide the SWP a max of 75,000 AF of water to meet in-basin requirements through adjustments in COA accounting.
CVPIA 3406(b)(2)	Dept of Interior 2003 Decision	Same
Allocation	800,000/YR, 700,000/YR in 40-30-30 Dry Years, and 600,000/YR in 40-30-30 Critical years	Same
Actions	1995 WQCP, Fish flow objectives (Oct-Jan), VAMP (Apr 15- May 16) CVP export restriction, 3000 CFS CVP export limit in May and June (D1485 Striped Bass continuation), Post (May 16-31) VAMP CVP export restriction, Ramping of CVP export (Jun), Upstream Releases (Feb-Sep)	Same
Accounting Adjustments	Per May 2003 Interior Decision, no limit on responsibility for D1641 requirements no Reset with the Storage metric and no Offset with the Release and Export metrics,	Same
CALFED Environmental Water Account	None	None

CALSIM II includes a hydrology developed jointly by DWR and USBR. Water diversion requirements (demands), stream accretions and depletions, rim basin inflows, irrigation efficiency, return flows, non-recoverable losses, and groundwater operation are components that make up the hydrology used in CALSIM II. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical sequence of monthly stream flows to represent a sequence of flows at a future level of development. Adjustments to historic water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions.

San Joaquin River basin hydrology is developed using fixed annual demands and regression analysis to develop accretions and depletions. The resulting hydrology represents the water supply available from Central Valley streams to the CVP and SWP at a future level of development.

CALSIM II uses DWR's Artificial Neural Network (ANN) model to simulate the flow-salinity relationships for the Delta. The ANN model correlates DSM2 model-generated salinity at key locations in the Delta with Delta inflows, Delta exports, and Delta Cross Channel operations. The ANN flow-salinity model estimates electrical conductivity at the following four locations for the purpose of modeling Delta water quality standards: Old River at Rock Slough, San Joaquin River at Jersey Point, Sacramento River at Emmaton, and Sacramento River at Collinsville. In its estimates, the ANN model considers antecedent conditions up to 148 days, and considers a "carriage-water" type of effect associated with Delta exports.

The CALSIM II CVP & SWP delivery logic uses runoff forecast information, which incorporates uncertainty and standardized rule curves (i.e. Water Supply Index versus Demand Index Curve) to estimate the water available for delivery and carryover storage. Updates of delivery levels occur monthly from January 1 through May 1 for the SWP and March 1 through May 1 for the CVP as water supply parameters become more certain. The south-of Delta SWP delivery is determined based upon water supply parameters and operational constraints. The CVP system wide delivery and south-of-Delta delivery are determined similarly upon water supply parameters and operational constraints with specific consideration for export constraints.

CALSIM II incorporates procedures for dynamic modeling of CVPIA 3406(b)(2) water and the Environmental Water Account (EWA), under the CALFED Framework and Record of Decision (ROD). Per the October, 1999 Decision and the subsequent February, 2002 Decision, CVPIA 3406(b)(2) accounting procedures are based on system conditions under operations associated with SWRCB D-1485 and D-1641 regulatory requirements. Similarly, the operating guidelines for selection of actions and allocation of assets under the EWA are based on system conditions under operations associated with SWRCB D-1641 regulatory requirements—**note that the EWA components are not incorporated into the analyses for Relicensing**. This requires sequential layering of multiple system requirements and simulations. CVPIA 3406(b)(2) allocates 800 TAF (600 TAF in Shasta critical years) of CVP project water to targeted fish actions. The full amount provides support for SWRCB D-1641 implementation. According to monthly accounting, 3406(b)(2) actions are dynamically selected according to an action matrix. Several actions in this matrix have defined reserve amounts that limit 3406(b)(2) expenditures for lower priority actions early in the year such that the higher priority actions can be met later in the year.

Feather River flow minimums and rates of changes are constrained in accordance with the 1967 agreement between DWR and DFG, Concerning the Operation of the Oroville

Division of the State Water Project for Management of Fish & Wildlife, amended by 1983 FERC re-licensing process. The 1983 agreement specifies that DWR release a minimum of 600 cfs into the Feather River from the Thermalito Diversion Dam for fishery purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline. In CALSIM II, this minimum required flow is imposed at Node 200A in the Feather River. Table 2 identifies the minimum flow requirement downstream of the Thermalito Afterbay outlet. Table 2 applies if Lake Oroville's surface elevation is greater than 733 feet MSL. Normal runoff is defined as the mean (1911-1960) April through July unimpaired runoff: 1,942 TAF.

Table 2: Feather River Minimum Flow Schedule

Percent of Normal Runoff (%)	Oct – Feb (CFS)	Mar (CFS)	Apr - Sep (CFS)
> 55	1700	1700	1000
< 55	1200	1000	1000

In addition, if during October 15 through November 30, the hourly flow is greater than 2,500 CFS then the flow minus 500 CFS must be maintained until the following March unless the high flow was due to flood control operation or mechanical problems. This requirement is to protect any spawning that could occur in over-bank areas during the higher flow rate by maintaining flow levels high enough to keep the over-bank areas submerged. In practice, the flows are maintained below 2,500 CFS from October 15 to November 30 to prevent spawning in the over-bank areas. In CALSIM II, this minimum required flow is pre-processed and input as time-series data imposed at Nodes 203 and 223 in the Feather River. CALSIM uses mixed integer programming to determine whether the 2,500 cfs limit is exceeded. The 1500 TAF Oroville storage criteria for determining this minimum flow is not modeled in CALSIM II.

Under contracts between DWR and each of the Feather River Service Area (FRSA) diverters, deliveries can be reduced, due to "Drought," by no more than 50% in any one year, and no more than 100% in any series of seven (7) consecutive years. In addition, reductions cannot exceed the percentages for the reduction in annual entitlements for water to be put to agricultural use by water supply contractors in the San Joaquin Valley. There are certain amounts of entitlement that are not subject to reduction: Joint Water District Board, 5 TAF; Western Canal, 145 TAF; Garden Highway, 5.13 TAF; Plumas Mutual, 6 TAF; Tudor Mutual, 210 AF; and Oswald, 150 AF. "Drought" criteria are defined in the contracts.

Total south-of-Delta SWP deliveries are determined based upon spring storage conditions at Lake Oroville and SWP San Luis and forecasted runoff available to the SWP. Based upon the annual delivery determined, the annual delivery is allocated as a percentage of contractual entitlement that is equal for all SWP contractors. A similar logic is used for North Bay Aqueduct contractor deliveries.

The CVP and SWP share the burden and benefits of compliance and excess flows as dictated in the 1986 Coordinated Operations Agreement (COA). Based upon the rules in the COA, specifically the definition of "Balanced Condition," the project shares of responsibility for In-Basin-Use are 75% for the CVP, and 25% for the SWP when storage is being drawn. In-Basin-Use includes project storage withdrawals (including Trinity River imports into the Sacramento River) for maintaining Delta water quality requirements. Also, based upon the rules in the Coordinated Operations Agreement, the project shares of Surplus Flows are 55% for the CVP, and 45% for the SWP. A project's share of Surplus flows includes project storage increase (after accounting for Trinity River imports into the Sacramento River) and Delta exports. The 1986 COA was negotiated in the context of SWRCB D-1485.

Water Rights Decision 1485 required export reductions for Striped Bass, and through agreements CVP provided support for these export reductions. In turn SWP wheeled, at priority at a later time, replacement water for the CVP. This replacement pumping was accounted for as a CVP export. No other wheeling is accounted for under COA. CALSIM II uses a simplified accounting of the COA. CALSIM II operates to COA sharing formulas to the extent possible within each time-step. Any outstanding imbalance in this sharing is ignored. In actuality, CVP and SWP operators will similarly allow an imbalance to necessarily occur during periods of the year, but will track and frequently attempt to reconcile these imbalances throughout the year. Due to the need to account more closely for CVP and SWP actions that require and are based on project specific accounting techniques, it is anticipated that "annual" COA accounting is required.

The 1986 COA makes no specification regarding the project obligations for reducing export under Water Rights Decision1641 export restrictions. Under informal operating arrangements, USBR and DWR have shared the remaining allowable export capacity. A 50%-50% split of export capacity sharing is assumed.

CALSIM II provides a reasonable planning level simulation of existing project operations, recognizing that the operating environment and regulatory requirements for the projects are in a constant state of transition and change CALSIM II is best utilized in a comparative mode. The results from an "alternative" simulation are compared to the results of a "base" simulation, to determine the incremental effects, of a project. The results from a single simulation may not necessarily represent the exact operations for a specific month or year, but should reflect long-term trends. The model developers advise caution when using CALSIM II to prescribe seasonal or to guide real-time operations, predict flows or water deliveries for any real-time operations.

1.3 DISSAGGREGATION OF CALSIM II OUTPUT FOR HYDROPS

The needs for data disaggregation derive from the differences of the temporal resolution of CALSIM II and HYDROPS.

CALSIM II simulates the operations of the SWP and CVP on a monthly time step over a synthetic 73-year hydrology based on water years 1922 through 1994. Due to its coarse temporal resolution, CALSIM II does not include flow ramping and stability criteria that are important considerations in daily operations. HYDROPS simulates weekly local operations of the Oroville Facilities, including power generation, on an hourly basis using the monthly water supply conditions from CALSIM II as the boundary conditions. Due to its refined temporal resolution, HYDROPS directly incorporates flow ramping and stability criteria as operational constraints. Therefore, there could be a discrepancy between the simulated weekly water budget by CALSIM II and the required weekly water budget for HYDROPS.

The potential discrepancy is illustrated in Figure 1, showing the comparison of the Feather River flow below Thermalito Afterbay Outlet in the period of June through October 1949. The CALSIM II-simulated weekly flow has a significant reduction between August and September, which exceeds the allowable ramping criteria (up to 1,400 cfs per week; see later discussion for more details) during the week of August 29 through September 5, 1949. In addition, when possible, DWR also prefers a more smooth change in flow throughout the year to reduce potential adverse effects on fishery and other natural resources. Therefore, adjusting the flow for the week of August 29 through September 5, 1949 for ramping criteria would require accompanied adjustments in other periods to preserve water budgets on a long-term basis.

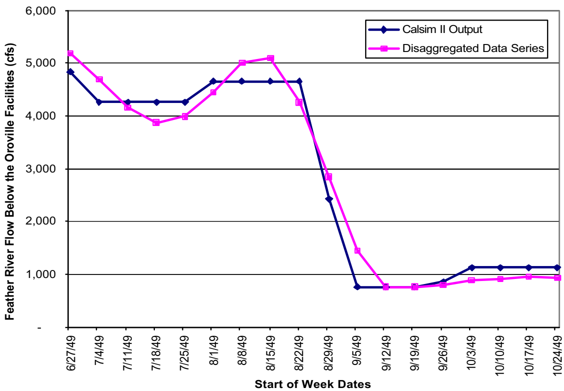


Figure 1. Comparison of Simulated Weekly Feather River Flows below Thermalito Afterbay Outlet before and after Data Disaggregation Process

The Feather River flow below Thermalito Afterbay Outlet is a key parameter for data disaggregation. This parameter is one of the common elements in CALSIM II and HYDROPS and is largely controlled by downstream water supply and regulatory needs (i.e., more insolated from local operations for power generation, fishery hatchery, and agricultural diversions within the Complex).

Because the water budget between the simulated operations of CALSIM II and HYDROPS on a weekly basis is not preserved, the data disaggregation process was based on water budget preservation for a longer period (more than one month; likely 2 to 3 months).

In addition, the data disaggregation incorporated additional operational criteria such as flow ramping and stabilization criteria, and DWR's preference in controlling flow fluctuations if possible.

The data disaggregation process can be detailed in four major steps.

Step 1. Curve-fitting the CALSIM II Data:

As shown in Figure 1, the weekly flows derived directly from CALSIM II results are jagged. So the first step to disaggregate was to smoothes the CALSIM II data with a curve-fitting routine. Although other methods for generating a relatively smooth operation from CALSIM II data were evaluated, curve-fitting proved the most useful because it yields results that are easy implemented. Highly accurate results were not yet necessary because this step only jump-starts the process, which includes additional corrections for refining the flow schedule.

The following equation was used for curve fitting by Microsoft Excel built-in tool for regression analysis:

$$Y = A + Bx + Cx^2 + Dx^3 + Ex^4 + Fx^5 + Gx^6 + Hx^7$$

Y is the weekly flow derived from CALSIM II results, x is the plotting position for a series of Y values, and A through H are regression parameters.

The minimum number of data points analyzed using this curve-fitting process matches the number of parameters. The maximum number of periods analyzed in a single regression depends on the variation of the data and the similarity in simulated operations throughout the period. The actual length of period used in single curve-fitting process was from trial and error. Typically the periods were about eighteen weeks.

The fitness of the resulting curve for weekly flows from the CALSIM II results was reviewed visually. If there were significant violations of minimum flow requirements, or the regression curve missed or exaggerated inflections in weekly flows from the CALSIM II results, adjustments were made to the number of periods analyzed and to the number of variables used, and the regression analysis was revised accordingly. Continuity is preserved by overlapping in data points between fitted curves. Long-term mass balance of the flow is generally preserved, but reinforced in the following steps.

Step 2. Correcting the Smoothed Curve for Operational Rules

The applicable operational rules include regulatory requirements and physical limitations. The regulatory requirements include minimum in-stream flow requirements, flow stability criteria, and flow ramping criteria; the physical limitations include the maximum and minimum storage capacity of Lake Oroville. The following describes these corrections.

A) **Correction for Minimum Flow Requirements:** This correction was to adjust the curve-fitted flows for minimum flow requirements, which were simulated in CALSIM II. The curve-fitted flows were compared against the minimum flows requirements and the greater of these two was used.

B) **Correction for Flow Stability Through the Fall Season:** If the Feather River flows rise above 2500 cfs between October 15 and November 30, the flow must be maintained through the spring. This flow stability criterion is designed to protect the spawning habitat on the Feather River. Typically, operators control flow below 2,500 cfs in this period excepting for flood control. Thus, the disaggregated flows were limited to a maximum of 2500 cfs during this period unless the storage of Oroville Lake exceeds 2,760 TAF.

C) **Correction for Ramping Criteria:** The ramping criteria for changing the flows on the Feather River are flow-rate dependent. These ramping criteria are to protect fishery habitat from rapid dewatering and to protect the river channel from erosion and scour due to high flow fluctuation.

Feather River Ramping Criteria for Reducing Flow (cfs)

Feather River Flow below Thermalito Outlet	Maximum Weekly Reduction
Less than 2,500	1,400
From 2,500 to 3,500	3,500
From 3,500 to 6,500	7,000
Greater than 6,500	14,000

For increasing the flows, the hourly limit is 5,000 cfs regardless of flow rate in the previous hour. However, this ramping criterion is not applicable if the storage of Lake Oroville is above 2,780 TAF, i.e., flooding conditions.

D) **Correction for Physical Constraint: Maximum Reservoir Storage:** The reservoir storage from step C was compared to the maximum reservoir storage level. If the flows in the previous steps had been decreased to the point the resulting storage of Lake Oroville is greater than its gross storage, an appropriate increase in release was made in order to keep the reservoir storage within the physical maximum.

E) **Correction for Physical Constraint: Minimum Reservoir Storage:** Similar to (D) above, a physical minimum storage was used to ensure releases did not draw the reservoir below its dead pool.

Step 3. Correction for Long-term Volumetric Consistency
Throughout the operational rule implementation process, the reservoir accumulated a volumetric difference compared to Step 1. Incremental corrections for this difference are added back in subsequent periods. The goal of the disaggregation is to have a correct mass balance over the course of a month, but due to limitations in changing the flow due to the previously mentioned operational rules, this may not be possible. The volumetric difference is accumulated until the time when the rules allow for it to be balanced.

Step 4. Review by SWP Operations staff
The entire disaggregation process and the resulting disaggregation flows were reviewed and approved by the SWP Operations staff for HYDROPS' use.

1.4 HYDROPS

HYDROPS™ is an hourly optimization model with a one-week time horizon. For the Oroville project, HYDROPS™ is set up to continuously run for an entire 73-year period. Operational boundary conditions within each week are provided with disaggregated monthly results from the CALSIM II model. These boundary conditions are the weekly starting and ending levels at Lake Oroville, and the weekly average flow at the Feather River node right below Thermalito Afterbay.

Given the boundary conditions set by CALSIM II as targets, the HYDROPS™ model optimizes hourly operations of the Oroville-Thermalito complex while meeting all facilities constraints and operational requirements.

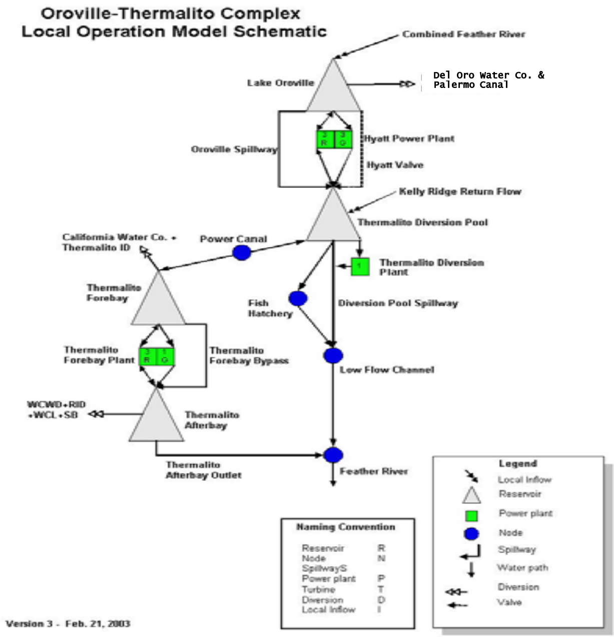
Hourly outputs from HYDROPS™ (including flow, generation and reservoir levels), will be used by the WQRRS model to simulate the temperature at various locations within, and downstream of, the Oroville project. The Temperature Control Actions (TCA), which include various operational measures on spill, generation and pump-back, were applied to meet temperature criteria, and these operational changes will then be fed back to HYDROPS™ for re-optimization.

Oroville HYDROPS™ Model Overview

The Oroville HYDROPS™ model includes all details of this hydropower complex, from engineering data of the facilities to the operational constraints.

Figure 2 illustrates how the Oroville-Thermalito complex was modeled in Oroville HYDROPS™. The gray triangles represent reservoirs, the green squares are power plants, and the blue circles are river nodes.

Figure 2: Schematic for Oroville HYDROPS™ Model



The relationship between reservoir storage and level is described as stage-storage curve. It could be an equation or a table of storage values versus level values. This relationship is stored in the database and used by the HYDROPS™ model to keep track of the amount of water coming in and going out of the reservoirs at any time step. Storage volume and level are updated every hour and head is calculated accordingly for the power equation.

A spillway is the main component of a dam. The spillway crest elevation and spillway rating curve information are used to calculate the amount of spill.

The generating and hydraulic capacities of a plant are used to set upper bounds for plant generation and discharge, respectively. The tailwater of each plant - a function of plant discharge - is used to calculate head for the power equation.

Each turbine/pump unit has efficiency that varies with the head and unit output. These units may also have a rough zone, at which the operation is not desirable for various reasons (vibration, noise, cavitation, etc.).

The power canal is modeled in HYDROPS™ to connect the Thermalito Diversion Pool with the Thermalito Forebay. Water in the power canal flows in both directions depending on whether the plants are generating or pumping.
There are three river nodes included in the Oroville HYDROPS™ model. They are: the Fish Hatchery, the Low Flow Channel, and the Feather River below the Thermalito Afterbay. Constraints on min/max flow can be set at these nodes.

Inputs from CALSIM II

Monthly results from the CALSIM II model are disaggregated to weekly values, which become inputs to HYDROPS™. These weekly values include:

- Inflow to Lake Oroville;
- Inflow at Kelly Ridge;
- Oroville evaporation;
- Thermalito evaporation;
- Palermo canal diversion;
- Butte County diversion;
- Thermalito ID diversion;
- Western canal diversion;
- Joint canal diversion;
- Feather River flow below Oroville-Thermalito complex;
- Oroville release;
- Hatchery diversion;
- Oroville end-of-week storage; and
- Oroville flood control limit.

The inflows, evaporation and diversions are used by HYDROPS™ as basic inputs. Oroville levels and Feather River flow are used as weekly targets. The Oroville flood control limit becomes a soft constraint for the maximum level at Oroville.

Operating Constraints

The Oroville HYDROPS™ model has two types of constraints: hard constraints that cannot be violated (i.e., physical limits and strict operating constraints), and soft constraints with associated penalty coefficients that can be traded off with other objective function coefficients (i.e., the soft constraints can be violated depending on the value of the penalty coefficients relative to other coefficients in the objective function).

<u>Min/Max Constraints</u>
The desirable range of operations can be set by defining min/max constraints on reservoir levels, flows at various locations, plant generation and discharge, and spill.

<u>Conditional Constraints</u>
Conditional operating constraints include:
- Conditional ramping constraints: Rate of change (level or flow) is conditioned upon flow at the Feather River node.
- Conditional flow constraints: Min/max flows at Feather River node are conditioned upon Oroville inflow.

<u>Special Constraints</u>
- Hyatt Valve Operation: Hyatt valve operates only when insufficient head exists for Hyatt or as specified as a temperature control action. The valve capacity is a function of head and is described in a rating table.
- Hyatt Plant Shutdown: Different turbine and pump units at the Hyatt plant will be shut down when the Oroville level drops to various thresholds.
- Power Canal Flow: Water in the power canal can flow in either direction, depending on whether the plants are generating or pumping. To ensure the water flowing in the power canal is hydraulically correct without making the models complicated, a special constraint was used to set levels at the Thermalito Diversion Pool the same as that at the Thermalito Forebay at all times.

Other Inputs

<u>Energy Price</u>
Hourly energy price indices from the California Energy Commission were used as the likely projection for future energy prices. These hourly prices are used by HYDROPS™ in optimization to maximize expected power revenues.

<u>Pump-back Trigger Price</u>

The DWR's pump-back procedures are mainly based on the pump-back trigger price, which includes 15% mark-up and $2/MW startup cost. These procedures are incorporated into a simple multiplier factor that is applied to the energy price for pump-back decision.

Maintenance Schedule

The user may specify when the units are out of service.

HYDROPS™ Setup for Benchmark Studies

In addition to the engineering data and CALSIM II inputs mentioned above, operating constraints for the Benchmark Study scenario are described as follows:

Starting Levels

Location	Long Term Average Level (ft)
Oroville	From CALSIM II
Thermalito Diversion Pool (DP)	223.31
Thermalito Forebay (FB)	223.31
Thermalito Afterbay (AB)	128.40

Ending Target Levels

Location	End-of-Week Target Level (ft)
Oroville	From CALSIM II
Thermalito DP	223.31
Thermalito FB	223.31
Thermalito AB	128.40

Level Constraints

Location	Hard Min (ft)	Soft Min (ft)	Soft Max (ft)	Hard Max (ft)
Oroville	340	n/a	from CALSIM	901
Thermalito DP	180	222	224	225
Thermalito FB	180	222	224	225
Thermalito AB	124	n/a	n/a	136.26

Flow Constraints

Location	Hard Min (cfs)	Soft Min (cfs)	Soft Max (cfs)	Hard Max (cfs)
Hyatt Valve	0	n/a	n/a	5,000
Fish Hatchery	100	n/a	n/a	100
Low Flow Channel	600	n/a	n/a	180,000
Feather River	700	*	*	180,000

Power Canal	0	n/a	n/a	17,000

**The soft min/max flow constraints at the Feather River node are calculated based on the weekly flow values from CALSIM II. These constraints ensure constant flow as much as possible at this location.*

Generation Constraints

Plants	Hard Min (MW)	Soft Min (MW)	Soft Max (MW)	Hard Max (MW)
Hyatt Plant	0	n/a	n/a	819
Thermalito DP	0	n/a	n/a	3
Thermalito FB	0	n/a	n/a	121

Generating Flow Constraints

Plants	Hard Min (cfs)	Soft Min (cfs)	Soft Max (cfs)	Hard Max (cfs)
Hyatt Plant	0	n/a	n/a	17,715
Thermalito DP	0	n/a	n/a	615
Thermalito FB	0	n/a	n/a	17,800

Pump-back Flow Constraints

Plants	Hard Min (cfs)	Soft Min (cfs)	Soft Max (cfs)	Hard Max (cfs)
Hyatt Plant	0	n/a	n/a	5,000
Thermalito FB	0	n/a	n/a	7,000

Spill Constraints

Location	Hard Min (cfs)	Soft Min (cfs)	Soft Max (cfs)	Hard Max (cfs)
Oroville	0	n/a	100,000	720,000
Thermalito DP	0	n/a	100,000	646,000
Thermalito FB	0	n/a	50,000	10,000
Thermalito AB	0	n/a	n/a	17,000

Conditional Ramping Constraints (apply only to the Feather River node when flow is at certain levels)

Ramping Rate (cfs/day)	Flow (cfs)
-200	0 - 2,500
-500	2,500 - 3,500
-1,000	3,500 - 6,500
-2,000	> 6,500
+5,000	> 0

Pump Back Trigger Price

The pump back trigger price was set at 1.21 for the Benchmark runs. The product of this factor and the hourly energy price becomes the cost of pumping.

Maintenance Schedule
There is no maintenance schedule specified for the Benchmark Study scenario.

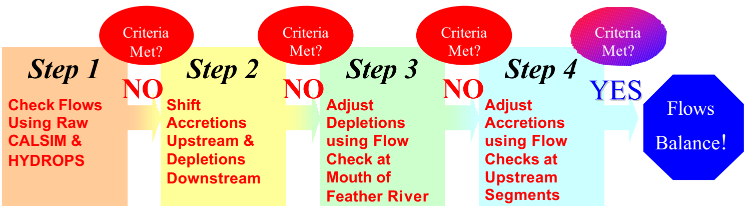
1.5 DISSAGGREGATION OF HYDROPS AND CALSIM FOR WQRRS

The WQRRS flow and temperature model of the Feather River receives input data from the CALSIM II and HYDROPS. CALSIM II provides monthly values for Feather River, Yuba River, and Bear River flows and depicts accretions and depletions to the Feather River as a single node. HYDROPS provides daily flow releases from the Thermalito Afterbay and Diversion Dam (headwater inflows). These flows needed to be reconciled or adjusted before using them in WQRRS so that flow requirements were properly simulated at the appropriate locations.

Accretion and Depletion Adjustment and Distribution

Two things needed to be determined when translating flows between models. The location of accretions and depletions along the river in the WQRRS model needed to be decided. Also, a method was developed to synchronize the monthly tributary inflows (Yuba and Bear Rivers and accretions) and withdrawals (depletions) with the daily varying headwater inflows (Thermalito Diversion Pool and Afterbay releases). Figure 3 presents the four steps of adjusting accretions and depletions to balance flows.

Figure 3. Four Steps of Adjusting Accretions and Depletions to Balance Flows



Step 1
The first step was to check the net river flow against the minimum required flow each day of the simulation period using the raw CALSIM II and HYDROPS inputs. If minimum flows are met at all locations, no adjustment of accretions and depletions is necessary.

Accretions and depletions can be added to the Feather River at any location along three reaches: (1) below the Afterbay outlet to the confluence with the Yuba River, (2) between the Yuba and Bear Rivers, and (3) between the Bear River confluence and the mouth of the Feather River. As a first trial, the monthly CALSIM accretions and depletions are split into three equal components (1/3, 1/3 and 1/3) for the three sections. When using this approach, minimum flows were not met for numerous periods of the benchmark simulation.

There are two reasons why minimum flows were exceeded in WQRRS but not in the CALSIM II budget. CALSIM II treats the river as a single node for which minimum flows are ensured, whereas WQRRS considers the spatial variation of inflows and withdrawals and net flow at each reach of the river. Second, HYDROPS flows can vary substantially from its monthly average flow. Short-term drops in HYDROPS headwater flows occasionally coincide with relatively large constant depletions. During times such as these, there is a short-term deficit of water in the river.

Step 2

The second step was to adjust the initial equal distribution of accretion and depletion flows to reduce the minimum flow exceedences after the first step. Accretions were shifted upstream, and depletions are shifted downstream to help short-term low flows in the river and large relative depletions. After a few iterations, a suitable distribution was determined to be 60%, 20%, and 20% for accretions, and 0%, 50%, and 50% for depletions (Table 3). Shifting flows in this manner caused a much greater level of compliance. SWP operations staff approved this final distribution.

Table 3 Distribution of Accretion and Depletion in the Feather River Temperature Model.

	Relative Amount by River Reach:		
	Reach 1: From Thermalito Outlet to Upstream of Yuba River Confluence	Reach 2: Between Confluences of Yuba & Bear rivers	Reach 3: Downstream of Bear River
Accretion	60%	20%	20%
Depletion	0%	50%	50%

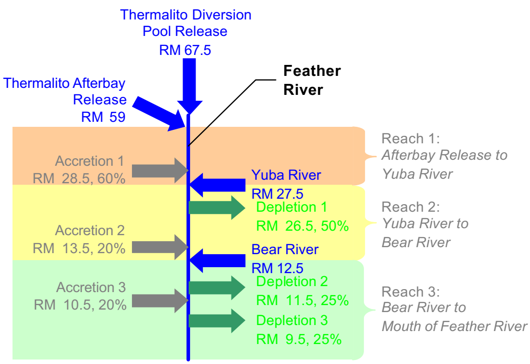
Table 4 shows the locations of accretions and depletions in the model. The specific locations of these inflows and outflows were selected in part to satisfy stability of the model. Large inflows and outflows from the model can cause internal numerical instabilities within the hydrodynamic solution. Thus locating the accretions and depletions was done in part with respect to numerical stability.

Table 4-- Location of Accretions and Depletions in the Feather River Temperature Model.

	Location (River Miles) of Accretion and Depletion by River Reach:		
	Reach 1	Reach 2	Reach 3
Accretion	28.5	13.5	10.5
Depletion	N/A	26.5	11.5 & 9.5

Figure 4 is a schematic of the Feather River that summarizes the location and distribution of accretions and depletions. The Thermalito Diversion Pool Release, Afterbay Release, and Yuba and Bear River inflows are shown as blue arrows. The accretion inflows are shown in gray, and the Depletions are green. The color-shaded regions in the background indicate reaches 1, 2 and 3. The river mile is indicated next to each inflow and withdrawal, and the accretions and depletions also indicate their relative distribution in percent.

Figure 4. Schematic of Feather River Showing Locations of Inflows and Withdrawals in River Miles and Accretion and Depletion Distribution Percentages



Step 3

Because minimum flow requirements were not met at all times after Step 2, a third step to adjust the constant monthly depletions to better align with daily headwater fluctuations was required. A method was developed to redistribute depletions so that minimum flows were met at the mouth of the Feather River. This method subtracted from depletions when necessary, and later increased depletions when possible with respect to the flow requirement. In each case depletions were conserved over the adjustment period.

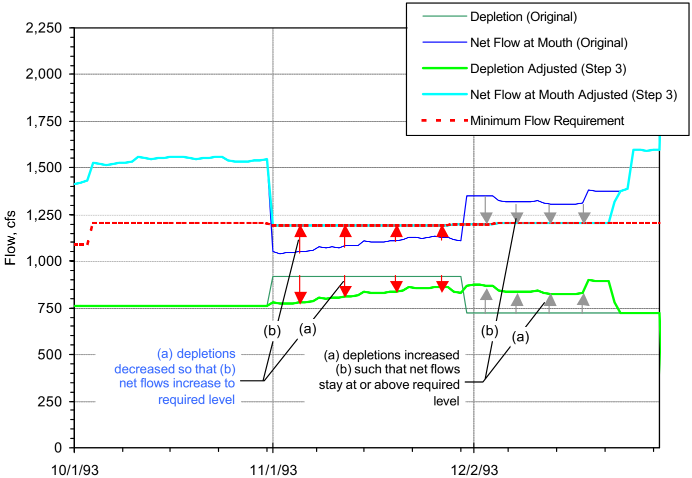
An example of Step 3 using data from the Benchmark scenario is shown in Figure 5. This plot spans the three-month period from October to December in 1993. The first line in the legend shows the original, monthly depletion flows from the CALSIM II model (dark green line). Depletions are constant over each month in this period, and they vary from just over 750 cfs to almost 1000 cfs, and then down to under 750 cfs. The thin blue line shows the original net flow in the river at its mouth. Net flow was calculated as the sum of the headwater (HYDROPS Thermalito Diversion Pool plus Afterbay releases), Yuba, Bear, and total accretion inflows minus the total accretion outflows as follows:

$$\text{Net River Flow} = \overset{\textit{Sum of}}{\sum} \begin{array}{l} \text{Diversion Pool Release} \\ \text{Afterbay Release} \\ \text{Yuba River Inflow} \\ \text{Bear River Inflow} \\ \text{Accretion Inflow} \end{array} - \text{Depletions}$$

In Figure 5, the net flow is above the minimum flow requirement (dashed red line) in October. No adjustment is necessary during this time. In November, however, it drops below the flow requirement. To increase the net river flow in November, depletions were adjusted. Depletions were reduced such that the net flow would increase to the required flow. The light green line shows the adjusted or decreased depletions in November that are below the original depletions. The light blue line indicates the resulting adjusted net flow. This line lies on top of the dashed red line in November showing that it just reaches the minimum level. The red arrows in Figure 3.2.5 indicate the direction flows changed (depletions down and net flows up) in order to maintain November flow requirements.

For each reduction in depletion, a corresponding increase in depletion was made so that total depletions over the period do not change. In Figure 3.2.5, the original net flow (blue line) rises above the minimum level in December. Thus there is water available to subtract from the river, i.e. depletions can increase. Net river flows are reduced, and depletions are increased until the last week in December when the deficit of depletions has been made up. Depletions that were lowered in November are added in December so that the overall depletions within the period do not change. The gray arrows in Figure 5 indicate the direction flows were changed in December.

Figure 5. Adjustment of Monthly Depletions to Meet Minimum Flow Requirements at the Mouth of the Feather River



Step 4

The third step considered the overall flow requirement at the mouth of the Feather River, but it did not consider requirements upstream of the confluence with the Yuba River, or between the Yuba and Bear Rivers. Step 4 was needed to adjust flows at the segments above the Bear River. A method similar to that of Step 3 was used to rearrange accretions and maintain minimum flows. Adjusting accretions was required only a handful of times in the 73-year Benchmark period, and adjustment were typically required for a few days. This final step brought flows into compliance for the remaining periods. Thus flows in each river reach meet flow requirements for all days of the simulation period.

1.6 WQRRS

General Description of WQRRS

WQRRS is a hydrodynamic and water quality simulation model for river and reservoir systems, distributed by the Hydrologic Engineering Center of the US Army Corps of Engineers (US Army Corps of Engineers 1978). This model divides reservoirs into stacked layers of water and divides rivers into segments, which serve as control volumes for water balance and heat budget calculations. WQRRS is a one dimensional model; it calculates the temperature profile of a lake in vertical direction and the temperature file of a river in horizontal direction.

To adapt this model to a particular system, geometric data of reservoirs, such as depth-area and depth-volume relationships, are compiled and input to the model. The elevations of intakes and outlets of hydro power plants are specified. Hourly inflow, outflow (power plant releases and spills), and meteorology data are used to drive the model, which performs hourly calculations to predict the lake surface elevations, lake temperature profiles, coldwater volume, and temperatures at various locations specified in the system.

Oroville WQRRS Model Overview

WQRRS simulates Lake Oroville, Thermalito Diversion Pool, Thermalito Forebay, and Thermalito Afterbay as the stratified reservoirs. WQRRS simulates the Feather River from the Diversion Pool to the confluence with Sacramento River as a vertically mixed river. WQRRS provides an integrated simulation of temperatures for various locations in the Oroville Facilities as well as the Feather River and has been adapted and calibrated with field data collected in 2002 and 2003. A detailed report on the calibration and verification is under preparation.

Weather

For the hourly simulation, WQRRS accepts hourly input data of meteorological conditions that include short wave radiation, long wave radiation, air temperature, dew point temperature, atmospheric pressure, and wind speed. These data vary both hourly and daily due to the ever-changing weather conditions. During the model calibration, actual meteorological data were used in order to predict the temperatures measured real time in the field.

Lake Oroville Inflows and Temperatures

The division of the inflow into Lake Oroville from the various forks was estimated from historic flow records. These flow splits are detailed in Table 5.

Table 5 Percentage of inflows to Lake Oroville among its Tributaries

	North Fork				
Month	North Branch	West Branch	Mid. Fork	South Fork	Total
1	0.59	0.06	0.31	0.04	1.00
2	0.56	0.06	0.34	0.04	1.00
3	0.54	0.06	0.35	0.05	1.00

4	0.55	0.06	0.35	0.04	1.00
5	0.54	0.06	0.36	0.03	1.00
6	0.58	0.06	0.31	0.05	1.00
7	0.70	0.06	0.18	0.06	1.00
8	0.77	0.03	0.12	0.08	1.00
9	0.76	0.05	0.11	0.08	1.00
10	0.75	0.06	0.16	0.03	1.00
11	0.67	0.06	0.25	0.02	1.00
12	0.60	0.06	0.31	0.03	1.00

The table showed that two major tributaries of Lake Oroville are North Branch and the Middle Forks. Their flow fractions appeared to be constant for much of the year, i.e. 0.54 – 0.6 for the North Branch and 0.31 – 0.36 from December and January through June. The patterns changed particularly in August through October, when the North Branch fraction increased to 80% and the Middle Fork fraction decreased to 10%. This change in the summer and fall may be due to increased hydropower operation on the North Branch.

The temperature of combined inflow was estimated to vary according to the seasons. However it was necessary to separate hydropower generation flows, which are relatively cold in the summer and fall, from natural or unimpaired stream flows..

Very large temperature fluctuations occur in summer and fall below the Poe Powerhouse on the North Fork. Therefore the North Fork flow is further split into regular stream flow and hydropower release as shown in Table 6.

Table 6 Estimated Flow Split for PG&E Hydro Release.

	North Fork		North Branch Split				
Month	North Branch	West Branch	Stream	Hydrop. Oper.	Mid. Fork	South Fork	Total
1	0.59	0.06	0.59	0.00	0.31	0.04	1.00
2	0.56	0.06	0.56	0.00	0.34	0.04	1.00
3	0.54	0.06	0.54	0.00	0.35	0.05	1.00
4	0.55	0.06	0.55	0.00	0.35	0.04	1.00
5	0.54	0.06	0.54	0.00	0.36	0.03	1.00
6	0.58	0.06	0.58	0.00	0.31	0.05	1.00
7	0.70	0.06	0.18	0.53	0.18	0.06	1.00
8	0.77	0.03	0.08	0.68	0.12	0.08	1.00
9	0.76	0.05	0.08	0.68	0.11	0.08	1.00
10	0.75	0.06	0.11	0.63	0.16	0.03	1.00
11	0.67	0.06	0.25	0.42	0.25	0.02	1.00
12	0.60	0.06	0.60	0.00	0.31	0.03	1.00

This split assumes minimal hydropower operation from December through June, and gradually increasing operation beginning in July and ending in November. The total flow was split such that the in-stream flow reflected similar flow fractions from other forks in the summer months, i.e., approximately 8% of the total inflow during the summer. The remaining portion of the North Branch flow is assumed to be from hydropower operations.

By separating PG&E flow releases from the total inflow to Lake Oroville, WQRRS now has two tributary inflow temperatures into Lake Oroville. One tributary represents natural or non-impaired flow and temperature variations, and the other tributary represents the effects of hydropower operations in the summer and fall.

The natural tributary inflow temperatures to Lake Oroville were estimated based on a regression with air temperature data. A regression relationship was developed using available observed tributary inflow temperature data from August 2002 to the end of December 2003, the calibration period. The correlation between air temperatures and inflow temperatures was good, as indicated by an r^2 value of 0.875. The following equation shows the relationship between air temperature and natural inflow temperature used in the benchmark and other simulations:

$$T_{\inf low} = 0.7919 \times T_{air} + 0.2609$$

Hydropower inflow temperatures were estimated using observed data in the stream below the PG&E Poe Powerhouse. Data were available for several months when hydropower operation was believed to occur (mainly August through October) of the calibration period in 2002 and 2003.

In 2002, the average minimum daily inflow temperature from below the Poe Powerhouse from the beginning of September to the end of October was 10.5 deg C (51.0 deg F) with a minimum of 6.5 deg C (44.0 deg F). From August to the end of November of 2003, the average minimum daily temperature was 14.5 deg C (58.1 deg. F.) with an absolute minimum of 6.9 deg C (44.5 deg. F).

The average minimum temperature in the stream below Poe Powerhouse was used as an indicator of hydropower temperatures because these temperature data represents a combination of natural stream flows and powerhouse releases. It is not known how the averages of the observed data were calculated, or if they are flow-weighted. However, the relatively low average and absolute minimum temperatures in summer and fall indicate cold water inflows from hydropower operation in otherwise warm weather periods. From the data with an average of approximately 51 to 58 deg. F and minimum of 44 deg. F, an estimate of 50 deg C was applied to the hydropower inflows in the Benchmark Future Benchmark and other scenarios.

Hyatt Intake Shutter Settings

Actual operation records of dry years (1990, 1991) and wet years (1997 and 1998) were analyzed for the historic shutter settings of Hyatt plant. These shutter settings were analyzed together with water surface elevations in Lake Oroville to develop the shutter settings for the first pass of WQRRS simulation.

River Flows

Actual flows of the Oroville Facilities and Feather River fluctuate hourly and daily. For the 73 years benchmark simulation, CALSIM II provided monthly flows of Yuba River and Bear River, which contribute tributary flows to the Feather River. It also provided the accretions and depletions that occurred along the river. For the benchmark simulation, a procedure was developed to disaggregate the monthly flows to weekly flows and then hourly flows. Accretions and depletions were assumed to occur in three points. The accretions occurred at RM (river mile) 28.5 (above Yuba River), RM 13.5 (above the Bear River), and RM 10.5 (below the Bear River). The depletions occurred at RM 26.5 (below the Yuba River), RM 11.5 and RM 9.5 (both below the Bear River). Accretions and depletions were proportioned to maintain minimum flow in the river at all river segments all the time. The majority of accretions occur upstream of the Yuba River, and depletions occur in equal proportion above and below the Bear River.

A stage-flow study using the HEC-RAS model in concert with observed data was conducted for Feather River below the Diversion Dam. The study provides a cross section and invert elevation for every segment of the river segment as short as 0.02 miles. The river cross section and invert elevation data were used to determine the cross section and invert elevation of the WQRRS river segments, which vary from one quarter to half river mile in the upstream section of Feather River and one to two river miles in the downstream section of Feather River. WQRRS used the data to route the flow for Feather River dynamically using St. Venant's equation.

Temperatures of Tributary Flows and Accretions

Depletions are assumed to reflect the water at the ambient river temperature. Temperatures were estimated for tributary inflows and accretions. The accretions temperatures were set at the ambient temperature of the river at the location of the return flow. Thus, accretions do not change the temperature of the river, but only affect the flow volume in the river.

During the model calibration, two relationships between air temperature and inflow temperature for the Yuba River and the Bear River were developed using the 2002 data. These relationships were used to calculate the inflow temperatures.

Temperature Objectives

The temperature requirements for the Feather River Fish Hatchery are 52°F for September; 51°F for October and November; 55°F for December through March; 51°F for April through May 15; 55°F for last half of May; 56°F for June 1-15; 60°F for June 16 through August 15; and 58°F for August 16-31. A temperature range of plus or minus four degrees is allowed from the objective from April through November. There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook. From May through August, they must be suitable for shad, striped bass, and other warm water fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead trout and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to control water temperature at Feather River mile 61.6 (Robinson's Riffle in the low-flow channel) from June 1 through September 30. This measure requires water temperatures less than or equal to 65°F on a daily average. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

Actual temperature control actions are not systematically implemented. The actions Department operators take depend largely on the circumstances of the time. Typically the first action taken to control water temperatures to comply with hatchery objectives is the removal of one or more shutters from the Hyatt Intake structure. This removal will depend on the balance of units in use (three units take water from one intake, three from the other) and the temperatures at a particular depth. To mimic such decisions has proved rather cumbersome for modeling studies incorporating over 26,000 days. To simplify the decisions and assure consistent implementation, the temperature control actions detailed below were developed. Shutter pulls are broken into two actions, the first three shutters and then the rest of the shutters (if any are still in.) Likewise these actions may occur on any particular day or multiple days within a week, but to preserve the modelers' sanity, the actions are implemented for an entire week at a time.

Other actions include reducing or eliminate pump-back operations and minimizing peaking operations (depeaking). These actions may be preceded or be incorporated with shutter pulls depending on manpower status and concerns of the operators. For the sake of the modeling, these actions only occur after the shutter pulls have been exhausted. Although observed data suggests depeaking may be a viable action the modeling results did not reflect any reduction to hatchery temperatures from depeaking; to the contrary there was often a warming of water at the hatchery from this action. The potential effect of depeaking appears to exceed the model resolution that can be supported by the WQRRS; however, when using river valve, the power generation is depeaked to a large extent. For modeling purposes, we bundle these two actions together.

Often times, the stated objective for temperature control at the hatchery proves very problematic and some higher allowable (within +4 degrees) objective is targeted. It is also not uncommon for the hatchery staff to request temperatures lower or higher than the objective as conditions of the fish warrant. The following temperature objectives at the fish hatchery were used in the benchmark studies to determine the need for all but one of the related control actions:

April 1 to May 31	55 ^{o}F
May 16 to May 31	55 ^{o}F
June 1 to June 15	60 ^{o}F
June 16 to August 15	60 ^{o}F
August 16 to August 31	60 ^{o}F
September 1 to 30	56 ^{o}F
October 1 to November 30	55 ^{o}F
December 1 to March 31	55 ^{o}F

Because the use of the river valve reduces generating capability at Hyatt (for a given release target), and because use of the river valve increases maintenance concerns such use is only considered in extreme need. For modeling purposes the use of the river valve is limited to 1000 cfs. The following higher objectives were used to flag this final control action:

April 1 to May 15	55 ^{o}F
May 16 to May 31	59 ^{o}F
June 1 to June 15	60 ^{o}F
June 16 to August 15	64 ^{o}F
August 16 to August 31	62 ^{o}F
September 1 to 30	56 ^{o}F
October 1 to November 30	55 ^{o}F
December 1 to March 31	55 ^{o}F

The temperature objective for Robinson Riffle used in the Benchmark studies was 65 ^{o}F from June 1 to September 30.

Temperature Control Actions

The Department operates the Oroville Facilities to assure compliance with the temperature objectives at the hatchery and at Robinson Riffle. The actions implemented at any particular time reflect the conditions and assumptions of the time. Because these actions are so conditions specific, no one set of temperature actions can be assumed for use with the computer simulations. Therefore it was necessary to run the WQRRS model iteratively with human guidance. To help guide the Modeling

Team's work they employed a decision spreadsheet to quickly identify when an action may be needed to adjust the simulated operations.

Although both WQRRS and HYDROPS utilize an hourly time step, temperature control actions were implemented for an entire week at a time. To make the analyses more manageable, WQRRS was run in five-year increments. Different rules were used to both start and stop each temperature control action. To mimic operator foresight regarding weather conditions, forward-running seven-day averages of the daily temperatures along with multi-day exceedences were used to flag actions for a week at a time. The Benchmark analysis began with a comparison of the initial HYDROPS based water temperatures at the fish hatchery. The procedure continues with the following steps:

- If the minimum of the initial daily temperatures or the seven-day forward averaged daily temperatures exceeds the objective at the hatchery for more than three days in a week then the first TCA is flagged. The first TCA removes three shutters from each of the two intakes. Once the action begins the flagging criteria changes to an exceedence of the objective for any two days in the week. This less restrictive criterion avoids a premature end to the action. Note that the shutters are not necessarily replaced unless replacement of shutters has begun in the initial HYDROPS run.

- WQRRS is then re-run for the five-year increment. If the subsequent minimum of the initial daily temperatures or the seven-day forward averaged daily temperatures exceeds the objective at the hatchery for more than three days in a week then the second TCA is flagged. The second TCA removes all remaining shutters. Once the action begins the flagging criteria changes to an exceedence of the objective for any two days in the week. Again, note that the shutters are not necessarily replaced unless replacement of shutters has begun in the initial HYDROPS run.

- WQRRS is then run yet again for the five-year increment. If the subsequent minimum of the initial daily temperatures or the seven-day forward averaged daily temperatures exceeds the objective at the hatchery for more than three days in a week then the third TCA is flagged. The third TCA is the elimination of pump-back operations. Once the action begins the flagging criteria changes to an exceedence of the objective for any two days in the week.

- WQRRS is then re-run with alternate HYDROPS output reflecting the third action for the appropriate weeks. To expedite this process, HYDROPS runs reflecting the various combinations of potential TCA's were produced in advance. If the subsequent minimum of the initial daily temperatures or the seven-day forward averaged daily temperatures still exceeds the objective at the hatchery for more than five days in a week then the fourth TCA is flagged. The fourth TCA is the bypass of flow through the river valve equal to the lesser of 1000 cfs or maximum plant flow at that time. Once the action begins the flagging criteria changes to an exceedence of the objective for any one day in the week. This is the final TCA for water temperatures at the hatchery.

- WQRRS is then again re-run with alternate HYDROPS data reflecting the appropriate weeks of the third and fourth actions. If the minimum of the initial daily temperatures or the seven-day forward averaged daily temperatures exceeds the objective at Robinson Riffle for more than three days in a week then the fifth TCA is flagged. The fifth TCA adds 200 cfs to the Low Flow Channel (LFC). Once the action begins the flagging criteria changes to an exceedence of the objective for any two days in the week.

- A final run of WQRRS produces the final temperature regime for the five-year increment. The ending conditions are then used as starting conditions for the next five-year increment.

1.7 SUMMARY OF BENCHMARK SIMULATIONS

Two of the CALSIM II studies performed for the U.S. Bureau of Reclamation's update of its Operations Criteria and Plan (OCAP) were adopted for this scenario. These studies reflect the latest refinements to CALSIM II as of January 2004 and serve as the foundation to the Benchmark Scenarios presented here.

The following process was performed twice, once for the Existing Conditions Benchmark Scenario and once for the Future Conditions Benchmark Scenario.

- Disaggregate the monthly hydrology used in CALSIM II and the output from the CALSIM II Benchmark study into weekly values.

- Run HYDROPS based on the disaggregated CALSIM II data.

- Run WQRRS based on the initial HYDROPS run and identify any necessary adjustments to the assumed operations of the Oroville Facilities portrayed by HYDROPS for each week in order to account for water temperature objectives not assumed in the initial HYDROPS run.

- Re-run WQRRS based on altered HYDROPS runs that have incorporated the identified adjustments noted above and identify any additional necessary adjustments to the assumed operations of the Oroville Facilities for each week. Repeat process until all available adjustments have been incorporated.

- Run HYDROPS with all the identified adjustments to determine the final power generation and revenue for the benchmark scenario.

1.8 STUDY RESULTS

The results from all the models are best used comparatively. That is the differences between other studies and the Benchmark holds the greatest value to the user. The results in and of themselves can be used to approximate the probability of particular conditions occurring but should not be used as definitive predictions of any sort.

Because of the large quantity of data the model results contain, a complete depiction in this text is not practical. However, the Benchmark studies results are available to all who request them and have been compiled in a comprehensive database. An Excel based interface is also provided to help the user extract particular results of interest. Both database and tool are available on compact disc for personal computer use. For a copy please contact Lori Brown at 653-6124.

1.9 SUMMARY OF FINDINGS

Some findings of general interest from the conglomerate of completed Benchmark studies are presented below.

CALSIM

The average lake elevation by year type on the summer holidays Memorial Day, Independence Day, and Labor Day has been of much interest. CALSIM II cannot predict any particular water elevation in an unknown future; nevertheless a probability of a particular elevation at a particular time may be gleaned from the CALSIM II Benchmark studies results. These results are depicted in Figures 6 and 7.

Figure 6. Probability of Lake Oroville Water Surface Elevation for Summer Holidays-existing conditions

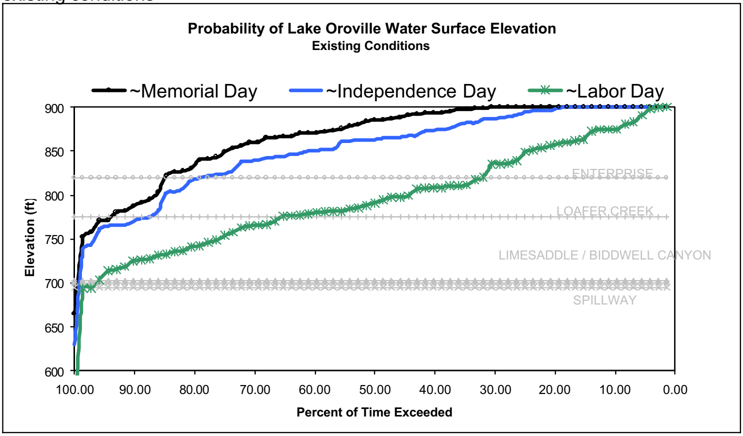
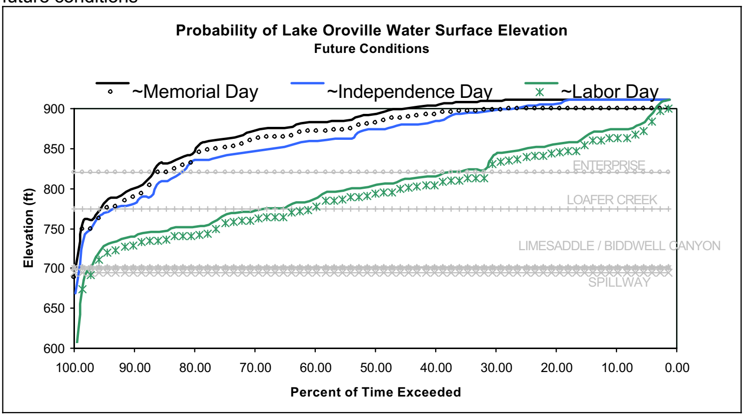


Figure 7. Probability of Lake Oroville Water Surface Elevation for Summer Holidays-future conditions



The CALSIM II Future Conditions Benchmark study suggest that 50% of the time on Memorial Day the surface elevation of Lake Oroville will be 882 feet or higher, 75% of the time the elevation will be 851 feet or higher. More of the results that can be determined from the Figures 6 and 7 are as follows:

75% Chance Elevations will be at or Greater	Lake Elevation with Existing Conditions	Lake Elevation with Future Conditions
Memorial Day	849 ft.	851 ft.
Independence Day	824 ft.	831 ft.
Labor Day	754 ft.	757 ft.

The above values are based on CALSIM II results for Oroville storage at the end of May, June, and August respectively

HYDROPS

From the HYDROPS results, the annual average power generation for the existing conditions Benchmark study was 2,753,000 MWH without any temperature control actions and 2,413,000 MWH with temperature control actions. This represents a potential reduction to power generation of more than 12 percent due to temperature control at the fish hatchery as modeled. These figures are broken down by year type as follows:

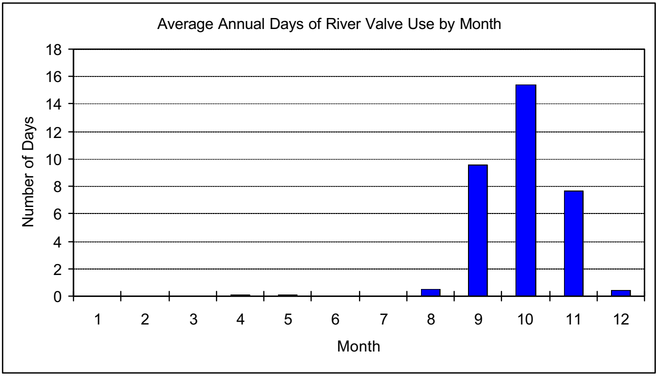
Average Annual Generation by Year type	Total Complex Generation (MWH) No TCA	Total Complex Generation (MWH) Benchmark, EC	% Change in total generation
Wet	3,802,988	3,542,328	-7%
Above Normal	3,051,637	2,611,814	-14%
Below Normal	2,548,163	2,165,524	-15%
Dry	2,181,212	1,822,650	-16%
Critical	1,603,057	1,267,023	-21%
All Years	2,752,614	2,412,624	-12%

WQRRS

The model results suggest that river valve release was required about 2,460 days from 1921 to 1994 (about 30 days per year) to try and achieve the temperature objectives of the fish hatchery. The total amount of flow released through the river valve was 67,000 acre-feet per year.

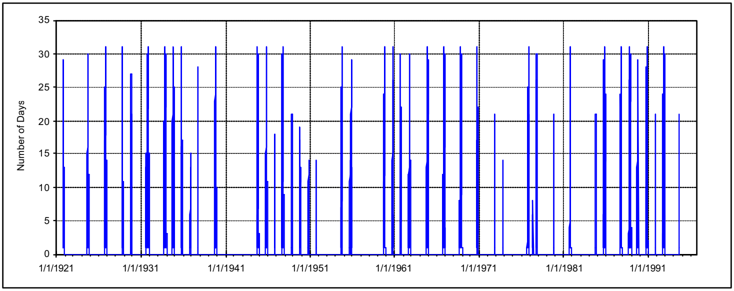
The average days of river valve use per year is shown in Figure 8 below. The days are averaged by month to those when through the year river valve use is most common. River valve releases are most common in October, averaging two weeks per month. River valve releases are also common in the September and November averaging one week per month. The rest of the year such releases are fairly uncommon.

Figure 8. Average Days of River Valve use Per Month



The use of the river valve through the full benchmark period is shown in Figure 9 below. In general the valve use is typically required in dry years and are not required in above normal or wet years. For example, river valve use is common during the dry periods of the early 1990s, the late 1970s, and early 1930. However usage is low during above normal periods such as the late 1950s and the early 1940s.

Figure 9. Days of River Valve use for Existing Conditions Study.



For questions or comments on this draft report please contact Arthur Hinojosa at 574-2655 or hinojosa@water.ca.gov.